

## **Detection of Submerged Sound Sources**

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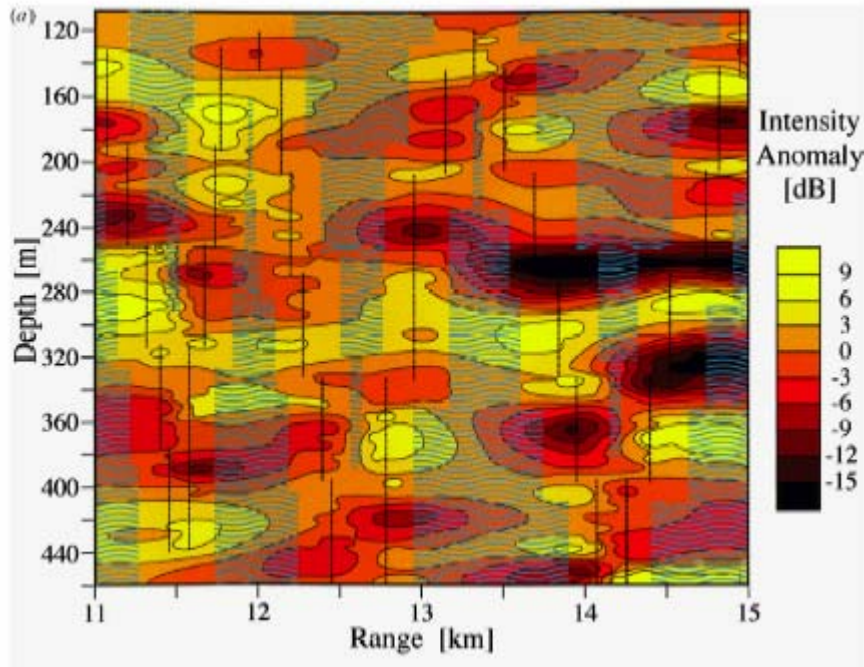
### **LONG TERM GOALS**

The long-term goal of the project is to improve our ability to detect submerged objects by employing our knowledge of the random spatial structure of sound in the ocean. The work will apply to passive sonar in the case when the submerged object is a sound source. It will also apply to active sonar when the submerged object is silent.

### **OBJECTIVES**

It has been established both theoretically and experimentally (Fig. 1) that sound, when propagating in the ocean, has a tendency to form ribbon like structures some of which can be of relatively high intensity. The scientific objective of this project is to establish the reasons why these ribbons form, to find out what determines their position and lifetimes, and especially how they change when the sound source moves vertically or the acoustic frequency varies. This will allow us to adapt the modes of deployment and operation of both passive and active sonar so as to optimise target acquisition.

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**Figure 1. High Intensity Ribbons**

*[Intensity from a sound source observed in the Mediterranean showing ribbons of high intensity some tens of meters thick extending for over a kilometer]*

## APPROACH

Although it is known that scattering by irregular ocean features such as internal waves and turbulence leads to the development of the ribbons (Fig. 1) it is not known why, once formed, they stretch so far through further scattering features. Nor it is known how they behave when the source moves. We propose to use numerical simulations of acoustic propagation in a scattering medium to study these questions. When a strong ribbon appears in the simulations the summed phase change associated with the scattering medium over the region of propagation leading to the ribbons can be determined. Thus the medium could be expressed as an "equivalent phase screen". Using modification of the theory of scattering by deep phase screens it may then be possible to associate a ribbon with a particularly large phase feature in the "equivalent phase screen". This would allow us to obtain statistical estimates of the spacing and strength of the ribbons.

Simulations would allow us to move the source while keeping the scattering medium the same. We could then find out how the ribbon structure behaved. It is not clear whether the ribbons also move with the source or stay substantially the same and merely change in their details. This information is vital if we are to make effective use of the ribbons in improving active sonar efficiency. It is also planned to develop the theory of intensity fluctuations in the case of a moving source. This will involve solving the fourth moment equation for a point source acoustic field in the general case when both source and medium move.

The effect on the ribbons of varying the acoustic frequency can be studied by using numerical simulations. The medium is kept the same but the source frequency can be changed. The associated multi-frequency intensity fluctuation theory can also be used to throw light on this question.

Finally, the numerical simulation facility will allow us to demonstrate to Navy personnel the nature and effects of the random structure of acoustic fields in the ocean. This is intended to be informative as well as to stimulate active comment and interaction with the project on the part of the Navy. We hope that this will lead to the knowledge flowing from the project finding useful applications in Navy practice.

Dr. B. Uscinski, the Principal Investigator, will carry out the theoretical aspects of the project in Cambridge, with some of the basic numerical simulations needed to support them. Dr. D. Rouseff will employ the more sophisticated numerical simulation packages available in APL, Seattle, in order to demonstrate the ribbon effect in a realistic ocean situation, and pursue methods for improving target acquisition times.

## **WORK COMPLETED**

### **Theory**

The theory of intensity fluctuations for the case when both source and medium can move has been completed by solving the appropriate parabolic fourth-moment equation. Some specific cases have been studied and examples given. A paper has been written entitled "Intensity Fluctuations in a Moving Random Medium" by B.J. Uscinski, and has been accepted for publication in the Journal "Waves in Random and Complex Media". This article will appear in the next issue of this Journal in 2005.

Another paper has been written giving a theoretical explanation of the extended acoustic ribbons observed in experiment and numerical simulations. The article entitled "High Intensity Ribbons in Multiply Scattering Media" by B. J. Uscinski and M. Spivack has been accepted for publication in the Journal "Waves in Random and Complex Media" and is due to appear later this year.

The effect of acoustic ribbons and dark regions on array performance has also been investigated. We have shown that when a hydrophone array is used to determine the bearing of a target, false results can be obtained if there is a strong ribboning effect and the array processing does not take this into account. We have also shown that there is a certain upper limit on the length of an array imposed as a result of scattering by irregularities in the medium, such as internal waves or turbulence. No gain in performance will be achieved by an increase in array length in these circumstances.

### **Simulations**

Simulations of acoustic propagation from a point source in deep water have been carried out confirming the existence of the predicted high-intensity ribbons. The causes leading to these ribbons have been investigated and a satisfactory explanation given. A paper containing this material has been written and is now accepted for publication. The numerical simulation work has continued and is being extended to deal with the case when sound propagating in the random medium encounters a rough surface or bottom. This will allow us to study how the ribbons are affected in this case and can be applied to acoustic propagation in shallow seas or close to the surface of a deep ocean. Both these situations are relevant to current Navy interests.

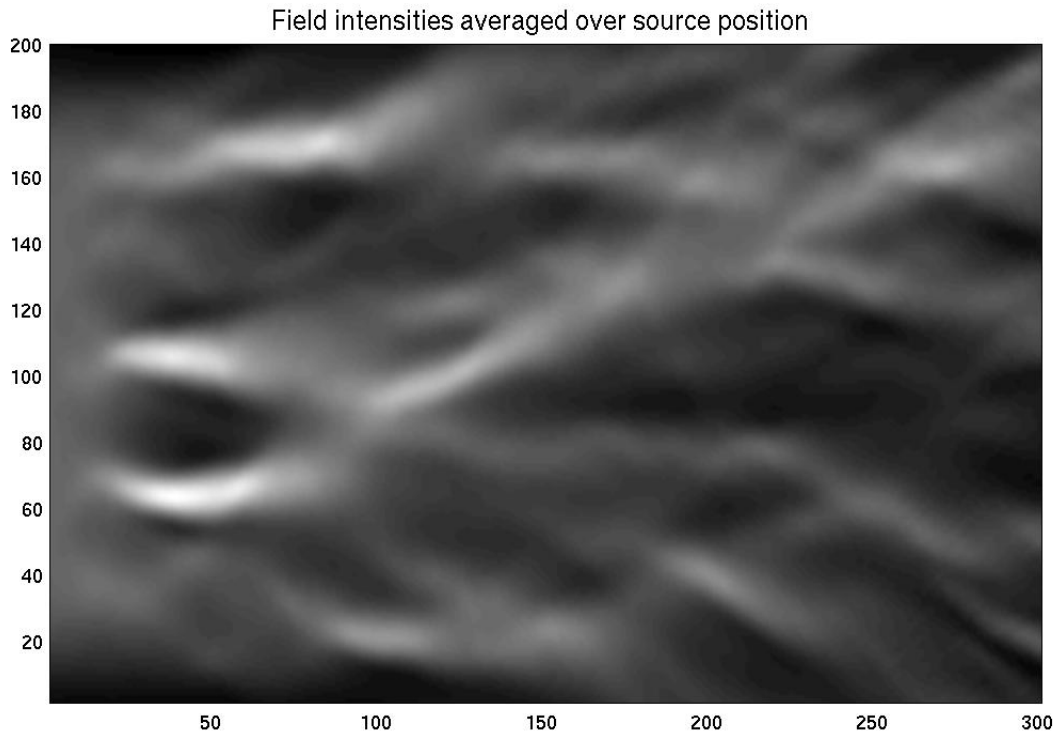
## Lectures And Visits

The lecture course on Wave Propagation in Randomly Scattering Media was delivered at the Applied Physics Laboratory, University of Washington, Seattle (our NICOPS partner) in June 2005. It was attended by about 20 students from both Oceanography and Electrical Engineering. A very full set of notes covering the course was issued. Some of the contacts with younger members of APL thus initiated are now continuing.

## RESULTS

The theory of intensity fluctuations for a moving point source and medium now allows us to investigate these effects fully in all scattering regimes and ranges of propagation. Some unexpected results have been found already, for example apparent reversals of velocity of a moving medium can now be explained in terms of velocity shear in the medium. Also the theory provides an explanation for the fact that in a uniformly moving medium the pattern velocity is twice that of the medium. There is much scope for further investigations based on the theoretical expressions obtained.

The numerical simulations have provided not only a confirmation of the existence of the high-intensity ribbons, but have also shown that changes in the vertical position of the source do not lead to major changes in the ribbon structure. The positions of the main ribbons remain the same and only the details change. This confirms the theoretical analysis that predicts that the position of a high intensity ribbons is associated with the local properties of the random medium in that area. In fact we have shown that if the cumulative phase change imposed by the medium in a particular direction is large initially then a high intensity ribbon will inevitably be produced. Thus, changing the position of the source has the effect rather of illuminating different parts of the medium and producing any high-intensity ribbon that may be associated with that particular region of medium. The same remarks can be made for a source that produces a beam (it can be even a fairly wide beam) and remains in the same vertical position but varies the vertical angle of the beam. The ribbons do not change much but the beam simply illuminates the ribbons appropriate to the different parts of the medium. This fact can be clearly illustrated by moving the source through the full range of vertical positions for the same realization of the random medium and averaging the resulting acoustic intensity. If the ribbons moved significantly as the source moved then the mean intensity would be virtually uniform since the high and low intensities of the moving ribbons would average out. In actual fact, as we see from Fig. 2, the average result displays distinct high intensity ribbons and very low intensity patches. This can only be so if the main ribbon structure does not move significantly as the source moves.



***Figure 2. Intensity pattern averaged over a vertical distribution of source position.  
[Intensity pattern averaged over all vertical source positions. The result shows that distinct high  
intensity ribbons and low intensity regions remain]***

These characteristics of the changing intensity pattern as source position is moved continuously can be seen at <http://www.damtp.cam.ac.uk/user/ms100/randommov.gif> and the behaviour as the beam angle varies can be seen at <http://www.damtp.cam.ac.uk/user/ms100/angle.mpg>. We note that several places both near to and far from the source are never significantly insonified.

There is considerable practical significance in the above results. They mean that not much advantage will be gained by changing the depth of an active sonar if we hope by this to catch a possible target with one of the higher-intensity ribbons. On the other hand for an underwater vehicle it means that once it can find a "quiet region" outside a high intensity ribbon it stands a good chance of remaining in it despite the efforts of the active sonar operator. There is clearly a lot of work to be done with these results in order to assess their operational impact fully.

Finally, the numerical simulation techniques have been extended to include the effect of a varying sound speed profile on propagation in a random medium. This allows us to look at the presence of a sound channel and makes it possible to deal with more realistic ocean scenarios.

## **IMPACT/APPLICATIONS**

An understanding of how the acoustic ribbon structure behaves as the source and medium move is essential in order to maximise the efficiency of operation of both active and passive sonars. It should enable us to increase the time for which a submerged object is insonified by active sonar and thus maximise the chance of detection. Clearly this is important in cases when we need to know whether a submerged object is in the vicinity of some valuable surface vessel such as an aircraft carrier. A knowledge of the ribbon structure could also lead to improvements in underwater communications, for example where an acoustic link is used to direct a Remotely Operated Underwater Vehicle, to communicate between submarines, or to keep in contact with divers. On the passive side a knowledge of the ribbon structure can help an underwater vehicle to minimise detection by search sonar.

## **TRANSITIONS**

The results obtained in this phase of the contract are now being applied to the study of acoustic propagation in the China Sea by Dr. Dan Rouseff of APL (Washington University). This will eventually allow a three-dimensional picture of the fluctuating acoustic field in these shallow seas with their downwardly refracting sound speed profile to be produced. This will be of obvious operational value.

In the same way links have been established with U.S. Navy personnel engaged in the design and evaluation of the sonar systems of a new class of U.S. submarine. Our results should allow us to determine the limitations that acoustic fluctuations impose on the new sonars and also to develop methods for making the most efficient use of these systems.

## **RELATED PROJECTS**

In 2001 an Acoustic Shadowgraph method was developed and deployed in the North Greenland Sea in order to study near-surface convection. This produced a data set that supports the ribbon picture and can be used to illustrate the improvement in contact times that is the aim of this project (<http://stacks.iop.org/WRM/13/107>). Since that time the Shadowgraph equipment has been deployed elsewhere in the Greenland sea by the Alfred Wegner Institute (Germany) to study similar effects there and a new data set will soon be available allowing us to study sonar performance in this different part of the ocean.

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